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GRAPHITE - NATURAL AND MANUFACTURED

BY

G. RICHARDS GWINN

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December 1943.

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

GRAPHITE - NATURAL AND MANUFACTURED[1]

By G. Richards Gwinn[2]

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INTRODUCTION

The mineral graphite, a form of carbon, has been known for hundreds of years, and was first used commercially as a coloring agent. Its true identity, however, was not recognized until the end of the eighteenth century, and its commercial development did not become extensive until near the close of the ninteenth century.

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[1] The Bureau of Mines will welcome reprinting of this paper provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Information Circular 7266."

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The first domestic graphite mine was Massachusetts, and it was also one of the first mining ventures of any kind in America. It was first secured by a grant to John Winthrop, Jr. (son of Governor Winthrop of Massachusetts), who purchased the tract from the Indian inhabitants between 1644 and 1658. The preliminary operation appears not to have been successful, but in 1738 mining was resumed, and one or more shipments were made to England, where the material brought 4 pence a pound.[3] A method for producing manufactured graphite was patented by Girard and Street in 1893, but the commercial method, an adaptation of the carborundum process, was patented by E. G. Acheson in 1896.

Graphite is a widely distributed mineral found in virtually every country of the world. Most occurrences, however, are of no economic importance because of poor quality, prohibitive mining and milling costs, inaccessibility, and poor location with reference to the industrial centers where graphite is used. The principal commercial deposits of graphite are found in Ceylon, Madagascar, Germany, U.S.S.R., the United States, Canada, Chosen (Korea), and Mexico. Included under Germany at present are the deposits in Czechoslovakia and Austria.

Graphite is commonly classified as natural and manufactured, and natural graphite may be divided into crystalline and amorphous. Crystalline graphite may occur as flake, lump, chip, or dust. Amorphous graphite is a commercial term only, as all graphite is crystalline, but grades in which the individual grains cannot be distinguished are classed by the trade as amorphous. Natural mixtures of crystalline and amorphous occur in all proportions.

During the past 25 years the uses of graphite have changed so greatly that different kinds are more nearly interchangeable in use. In 1914-18 the most important use was in crucibles, and domestic crucible makers demanded Celyon lump or chip graphite. In recent years the consumption of graphite in crucible has declined to rather small proportions, and crucible makers insist upon Madagascar flake of suitable mesh sizes. There are a few other specialities for which Madagascar flake or certain kinds of crystalline Ceylon graphite are desired in preference to qualities obtainable elsewhere. Fortunately, with respect to national security, the tonnage of graphite from these distant sources that can be considered as absolutely essential to military or even civilian industry is a relatively small fraction of the total compared with what it was even 12 years ago.

Graphite is a typical international mineral in that it is utilized mainly in the countries noted for their industrial activities, whereas the two islands,

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[3] Hayes, G. H., The Tale of Tantiusques, an Early Mining Venture in Massachusette: Proc. Am. Anti. Soc., Oct. 31, 1901. (Rev. in Mineral Resources 1913, pt. II, pp. 199-200).

Ceylon and Madagascar, which produce the major portion of the world's high-grade graphite, are virtually devoid of any manufacturing establishments requiring its use. The industry is therefore violently disturbed by wars. The lack of shipping and embargoes placed by France and Great Britian during the first World War to prevent supplies of Madagascar and Ceylon graphite from falling into the hands of the enemy brought some measure of prosperity to the domestic industry. Many of the numerous failures in the domestic industry after this war were attributed to the enormous stock piles that had accumulated in various parts of the world as well as to the fact that many domestic mills were built without adequate consideration of the aize or quality of the deposits. During the present war the domestic market has expanded again because of shortages of imported material, but extensive field and laboratory investigations by the Federal Geological Survey and the Bureau of Mines were carried out before the mills were erected. This, it is hoped, will not only eliminate many of the failures such as occurred after the previous world conflict, but will also increase the peacetime production of domestic graphite.

DESCRIPTION

Natural

Pure graphite offers an interesting combination of chemical and physical properties. It is available in several forms, each possessing individual characteristics.

Graphite is a soft, black, unctuous form of carbon, one of its three principal forms, the others being diamond and charcoal. Chemically, graphite is pure carbon, but physically it differs markedly from the diamond or charcoal. Graphite is one of the softest minerals (hardness, 1 to 2 on Mohs' scale); it is opaque even in finest particles, dark gray to black in color, extremely resistant to the action of acid or heat, and a good conductor of both heat and electricity. The specific gravity is 2.1.

The most common names for this mineral are graphite, plumbago, and black lead. Others, less frequently used, are potelot, crayon noir, carbo mineralis, and kish. Graphite was named by Johann Gottlieb Werner in 1789 from the Greek work "graphein," to write. The word was applied primarily to the large crystalline flake variety.

Plumbago is a trade term used primarily for massive graphite as found in Ceylon. Black lead is also a trade term and, like plumbago, is based upon the idea that prevailed throughout the Middle Ages that graphite was a form of lead, or at least contained that metal.

The purest graphite contains almost 100 percent carbon with very small amounts of silica. From this it may grade down to shales or slates containing only enough carbonaceous matter to make them black. Commercial graphite contains various impurities, the graphite carbon content ranging from as low as 30 or 35 percent for the paint trade to a maximum of 90 or 95 percent for crucibles or lubricants.

Manufactured Graphite

The term "artificial graphite" is a misnomer. "Manufactured graphite" is a better term, because it actually is pure crystalline graphite, the only artificial attribute being the method of production. The original discovery that graphite could be produced in the electric furnace was made in the course of experimenting with the effect of high temperatures on carborundum.[4] It was found that carborundum is decomposed at about 7,500° F, the silicon being vaporized and the carbon left behind. A process was later developed for making graphite from anthracite culm or petroleum coke with smaller amounts of quartz sand and sawdust.

Colloidal graphite. - This form is composed of manufactured graphite subdivided until the individual particles approach the dimensions of solids in true solution. These particles possess like electrical charges, which facilitate their suspension in liquids for long periods of time through the induction of repulsion fields that prevent intercollision, agglomeration, and settling.

GEOLOGIC OCCURRENCE AND ORIGIN

Geologic occurrence. - Graphite is found in nature in igneous, sedimentary, and metamorphic rocks. In igneous rocks it has been found in iron-nickel meteorites, effusive and plutonic rocks, dikes, and pegmatites. In sedimentary rocks it has been noted as small detrital particles that have been transported and deposited along with other clastic minerals, but because of its softness it may be ground to such small sizes that it is unrecognizable in these rocks. The most common occurrence is in metamorphic rocks, schists, gneisses, and metamorphosed limestones. Rarely does it constitute more than 10 percent of the rock, although in a few deposits it composes virtually the entire rock. In gneisses and schists it is present in small, thin flakes seldom over one-fifth inch in diameter, oriented parallel to the foliation and disseminated through the rocks like mica flakes in mica schists. The graphite flakes in limestone are similar in character but seldom show marked parallelism of orientation. In igneous rocks, including pegmatites, graphite also occurs in the form of unoriented thin flakes as well as pockets or lumps consisting almost entirely of graphite. In pegmatites the flakes are normally much larger and considerably thicker. Graphite also occurs in the form of veins in which other minerals may be entirely lacking. Many veins show foliation but do not readily split into thin flakes or fibers. Finally, graphite occurs in bedded deposits recognized as former coal beds altered to graphite.

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[4] Spence H. S. Graphite: Canada Dept. of Mines Bull. 511 1920 p. 114.

Origin.[5] - The origin of graphite is still problematical, and although much has been written, many questions remain unanswered. Bedded deposits of amorphous graphite formed from altered coal deposits are easily explained. The coal beds have been altered by igneous intrusions or by earth movements. Hot igneous rocks intruding the coal beds have provided the heat that has driven off the volatile constituents of the coal beds and converted the remaining carbon into the graphite form; heat generated during earth movements and compression of the coal beds brings about the same result.

The formation of flake graphite in metamorphic and igneous rocks, however, is not so clear. Flake graphite in gneisses, schists, and marbles is supposed to have been formed by dynamic metamorphic action upon organic matter derived from either plants or animals that were present in the original shales, sandstones, and limestones. The graphite was not formed in situ but moved to concentration centers, where the crystalline flakes were formed. Graphite in igneous rocks, including pegmatites, and in bedded deposits is believed to have existed as original gases of hydrocarbons or as oxides or carbon, which were present in volcanic lavas or derived from carbonaceous rocks cut by igneous intrusions.

Virtually all natural graphites, whether amorphous or crystalline, contain impurities of admixed mineral substances, the proportion of which is commonly greatest in the flake ores. In these ores the usual impurities are mica, calcite, quartz, feldspar, sulfide of iron (pyrite and pyrrhotite), and various silicates of lime, magnesia, and alumina. Where pronounced weathering of graphite schists has taken place, many of the above minerals have been altered to clayey material. In many such deposits considerable enrichment in graphite has resulted.

DOMESTIC DEPOSITS

Graphite has been reported in 25 States in the United States, and production in commercial quantities has come from 10. In recent years, however, the production of crystalline graphite had been insignificant and the output of natural amorphous graphite has been confined to a few hundred tons annually. Lump graphite resembling that produced in Ceylon has been mined near Dillon, Mont., but never in large amount. Flake graphite deposits in schists or gneisses have been mined in New York, Pennsylvania, Alabama,

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[5] Miller, B. L., Graphite: Am. Inst. Min. and Met. Eng., Industrial Minerals and Rocks, chap. 67, 1937, p. 333-4.

Texas, and California, and amorphous graphite has been mined in Michigan, Georgia, Rhode Isalnd, New Mexico, and Nevada.

The deposits of vein graphite near Dillon, Mont., occur near the southwest end of the Ruby Range of mountains, 15 miles southeast of Dillon, at an altitude of 7,500 to 8,000 feet, and are found in seams in limestone, as pockets in marble, and in schists associated with garnet, mica, quartz, and feldspar. The seams in limestone are 1 to 2 inches wide and presist over a considerable distance parallel to the bedding of the rock. Graphite in the marble occurs in irregular bunches and pockets at the contact of the marble and the igneous intrusion. In the schists it is intimately associated with garnet, quartz, feldspar, and mica. Production from these deposits has always been small.

Deposits of flake graphite, from which the largest amount of graphite has been recovered, are found in schists and gneisses that show various stages of weathering, ranging from the slightly altered schists containing the hard silicious ores of the eastern and southern Adirondacks to the weathered claylike masses typical of some of the Alabama deposits.

Deposits in the eastern and southern Adirondacks of New York State can furnish a large amount of flake if necessary, but the graphite is in hard rock and is interleaved with biotite mica, which makes separation difficult. The rock contains 4 to 5 percent graphite and therefore is higher grade than that occurring in Alabama. A small area near Suffern, N. Y., yields graphite in large flakes; but here, again, it is in narrow veins in fresh, unweathered gneiss and would necessitate mining and treating a large tonnage of rock to obtain a small amount of graphite. The graphite on the Western edge of the Adirondacks, near Morristown, is foundry-grade material, and the tonnage is small. The deposit is being worked down the dip of a plunging anticline, and as a consequence an increasing amount of overburden is encountered. The ore body has never been drilled, therefore, reserves cannot be estimated accurately.

Graphite has been mined intermittently in Pennsylvania for some time. The principal producing deposits are about 30 miles west of Philadelphia in the gneiss of Pickering Valley, Chester County. Graphite was recovered from the weathered portion of this gneiss from 1860 to 1920. Exposures are present in several old pits, and blocked-out reserves of 4 to 5 percent contain a large tonnage of flake material.

Deposits of moderate-size flake have been mined for a number of years in Alabama. Up to 1930, the production was 1,500,000 tons of material containing 2 percent graphitic carbon, 45 percent of which was plus 65-mesh. Flake deposits are best developed in a comparatively narrow belt approximately 4 miles wide and 60 miles long extending in a general northeastsouthwest direction through portions of Clay, Coosa, and Chilton Counties. The graphite occurs in weathered schist and is recovered by open-pit mining.

The Texas graphite deposits are found in the central region between Llano and Burnet in a fresh silicious schist. Both flake and amorphous varities are found, and the material is chiefly of foundry facing grade. A small tonnage of large flake could be recovered, but under present manufacturing processes the flake is too soft for crucible use.

Graphite in California occurs in Calaveras, Mendocino, Los Angeles, and San Diego Counties as flakes disseminated through a schist, which takes the form of a vein of schist in granite. The graphite is crystalline but in small flakes associated with quartz, feldspar, and minor amounts of mica and pyrite.

Graphitic slate classed as amorphous graphite has been produced in considerable quantities near L'Anse in Barago County, Michigan, and in the vicinity of Cartersville, Ga. In Rhode Island, amorphous-graphite beds were formed as a metamorphic product of coal beds. The coal beds were originally of moderate thickness but were folded and compressed by movements in the crust of the earth. Pressure was so intense that the coal was squeezed into pockets, which are joined by thin stringers consisting of coal, quartz, feldspar, pyrite, and other impurities. The heat generated by the movement and compression has driven off many of the volatile constituents of the coal, leaving impure amorphous graphite as a residue.

Amorphous graphite has also been formed by the alteration of coal in New Mexico. In Colfax County, along the Canadian River 7 miles southwest of Raton, igneous intrusions have altered bituminous coal to coke, and in a few places where the heat was particularly intense graphite was formed. Near Carson City, Ormsby County, Nev., a graphitic shale has been mined intermittently for amorphous graphite for some time.

FOREIGN DEPOSITS

Although graphite is found in virtually all countries of the world, Ceylon, Madagascar, Chosen (Korea), Mexico, Germany (which includes Czechoslovakia and Austria at present), the U.S.S.R., and Canada furnish almost 85 percent of the world output. Ceylon, Madagascar, and Chosen stand in the forefront because of the high quality of the graphite produced, the cheapness of native labor, and favorable mining conditions. Certain other localities have attained prominence because of low production cost and ease of transportation to the consuming markets. The large output of Czechoslovakia, for example, is the result as well as the cause of a great local industry utilizing its products.

Among the localities that are minor or potential producers are small deposits in England and Scotland; Berttula, Finland;[6] Vittangi and Norberg, Sweden; Senjen, Norway; the Machokos District in Kenya (East Africa); the Victoria and Wankie Districts (Rhodesia); Ugandi; British South Africa; Belgian Congo; the Bambari District of French Equatorial Africa; Portuguese East Africa; the Departments of Suceara, Gorji, and Nehedenti and the Carpathian Mountains, Rumania; Mt. Bopple, Queensland; Munglinup and Kenenup, Western Australia; Eyre's Peninsula, South Australia; Undercliffe, New South Wales; Chile, Paraguay, and Uraguay in South America; Shansi, Chihli, Kiangsu, and Hunan in China.

North America

Canada. - Graphite is widely distributed through Canada, but the only deposits that have been worked extensively are in southern Quebec and Ontario. The commercial deposits occur in gneiss, crystalline limestone, and contact metamorphic zones. For many years more than half the total Canadian output was furnished by the Black Donald mine at Calabogie in Renfrew County, Ontario. The occurrence consists of small flake containing local streaks of larger flake. The graphitic carbon content ranges from 60 to 80 percent. The graphitic material enclosed in limestone is of metasomatic origin and constitutes a replacement product of a certain zone of the limestone enclosing the deposit. The alteration of the limestone apparently involved intense graphitization accompanied by a corresponding lesser degree of silicification.[7] Manufactured graphite also is produced in Canada by the Acheson Graphite Co. in a plant at Niagara Falls, Ontario.

Newfoundland. - A considerable quantity of amorphous graphite has been produced near St. John's Newfoundland, and a few tons of vein graphite has been mined from Baffin Island, Labrador.

Mexico. - Deposits of amorphous graphite are found in the States of Sonora, Oaxaca, Guerrero, Hidalgo, Coahuila, and Baja California. The bulk of the production comes from mines in the State of Sonora about 20 miles south of La Colorado. The Oaxaca deposits are said to be too high in impurities to be commercially profitable.

The Sonora graphite was discovered in 1867, but commercial operations did not begin until 1895, when the U. S. Graphite Co., the present owner, purchased and developed the property. These deposits were originally coal seams enclosed in sandstone. The coal was altered to graphite by the heat that attended intrusion of granite into the sediments. There are at least six beds, two or three of which are of good quality and commercial size. The largest of them averages 9 to 10 feet in thickness, but, being highly folded, its thickness reaches a maximum of 24 feet. The graphite is exceptionally pure, selected samples containing as much as 95 percent graphitic carbon, the average being 80 and 85 percent.

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[6] Places noted in Finland, South Africa, Australia, Rumania, Sweden, and China are described or mentioned in Imperial Mineral Resources Bureau Report Graphite (1913-19), London, 1923.

[7] Spence, H. S., Graphite: Canadian Dept. of Mines, 1920, p. 37.

Europe

Austria. - Austria has greater resources of graphite than any country in the world, and before its dismemberment it annually produced over one-third of the world's output. The greater part of Austrian graphite is amorphous or so finely crystalline that it is classified as low-grade material. Production is derived from deposits in four distinct fields - the Kruman and Schwarzback districts of Bohemia, Moravia, Lower Austria, and Styria. The first two are in what is now known as Czechoslovakia and will be described under that country. Flake graphite occurs sparsely disseminated in gneiss in lower Austria in an area along the left bank of the Danube, between 39 and 55 miles west of Vienna. Amorphous graphite is found in graphitic slates situated between gneiss and mica schist, and in the Muehldorf district a steeply dipping bed of impure graphite occurs in crystalline limestone. The graphite produced in Lower Austria, even after refining, contains only 60 percent of carbon, and is employed chiefly in foundry facings. The graphite in the Styrian Alps is found in highly folded slates and limestones and is derived from the metamorphism of coal seams. The crude material runs 40 to 95 percent carbon and needs only hand sorting.

Czechoslovakia. - There are two graphite fields in Czechoslovakia - one in Bohemia and the other in Moravia. The deposits are irregular lenses of graphite schist interbedded with other metamorphic rocks. The major production from both fields is amorphous graphite, although a little crystalline material is mined in Bohemia. The refined product contains about 60 percent carbon and is used chiefly in the manufacture of foundry facings and cheap pencils.

Germany. - The graphite deposits of the Passau District in Bavaria are well known. The graphite occurs in lenses and pockets in gneiss and schists, and is of the disseminated flake type. The gneiss is deeply weathered in many places, and the graphite is therefore easy and cheap to mine. The average graphite content ranges from 20 to 30 percent. During the Middle Ages some of the alchemists' crucibles are said to have been made from this material.

Asia

Ceylon. - Deposits of graphite in Ceylon were reported in 1681, but commercial production began in 1827 and has been continuous since 1834. Graphite is widely disseminated through the rocks, but, except for a few flake deposits, all known commercial occurrences exist as veins formed by the filling of fissures in gneisses and schists. Graphite workings cover nearly the entire southern half of the Island. In the smaller veins and in a narrow zone between the main portion of many of the large veins and the country rock, graphite occurs as a mass of parallel fibres or needles normal to the vein walls. This fibrous material, known as needle lump, commands a premium price. Graphite in the larger veins has a coarse platy or foliated structure.

Although the veins usually consist entirely of graphite, some of them carry other minerals in appreciable amount. Pyrite and quartz commonly occur in disseminated form or as bands, and other accessory minerals are boitite, orthoclase feldspar, apatite, allanite, rutile, and pyroxene (usually augite). In some of the veins the material has been crushed by later tetonic disturbances.

The veins are worked either by open-cut methods or vertical shafts. Except for three of four properties, the mines consist of shallow pits or gougings in vein outcrops, which are leased to natives by the owners and are worked by hand methods.

Chosen (Korea). - The graphite industry of Chosen dates from about 1903, when the first exports were made. Most of the graphite in Chosen consists of beds and irregular lenses of amorphous material in slates and sandstones in the central and eastern parts of the country. In one district (Kyeing-Sang) are three seams having maximum mineable widths of 78, 13, and 46 feet, respectively. In northern Chosen are a few low grade deposits of flake graphite in schist and gneiss.

U.S.S.R. - Since the greater part of the graphite of the republic is in Siberia, all of the occurrences are described under Asiatic deposits. The graphite deposits in the Soviet Republic are of two principal types; one, amorphous graphite containing small amounts of pyrite, formed by the alteration of sediments by the intrusion of igneous rocks, and the other of regional metamorphic origin consisting of flake graphite in crystalline schists. Until recently the only graphite deposit in European Russia on which information was available was the Dzimorsk district in the Caucasus. Here amorphous graphite occurs in large beds or lenses with an average thickness of 1 meter and a known extension of 1,500 meters. As the result of geological exploration in the past 10 years, 37 graphite deposits of the contact metamorphic type have been found in the Ural Mountains. The largest deposits of this type are found in Eastern Siberia at the Kureishoe, Noginokoc, Botogolskac, and Sretenskoe mines. Large deposits of flake graphite are found at Soyuznoc (Malo-Khinganski), near the Amur River.

Africa

Madagascar. - The island of Madagascar probably contains the largest reserves of crystalline graphite of any section of the world. Graphite occurs in a belt of schists and gneisses almost 400 miles long. Most of the graphite consists of flake, but minor amounts of vein and amorphous material also have been found. The flakes are unusally large and constitute a much greater precentage of the schist than in any other large known deposits. Weathering has altered the rocks to a mixture of clay, graphite, mica, and quartz, which makes mining comparatively simple. The graphite content averages 10 to 12 percent but may be as high as 40 to 60 percent.

GRADES

Finished grades and classifications depend on the type of ore and separation used. Several grades and classes of varying particle size and purity may be produced from one mine. Finished grades of natural graphite are classified under flake, crystalline lump, chip or dust, and amorphous. The flake and crystalline varities, which are considered the purer and better grades, are distinctly different from the amorphous, the finished product of which has the appearance of black flour. In refining, several processes of separation may be used, including oil flotation, air separation, and washing.

Usually it is the physical character of the product that is of the utmost importance; the value of crystalline graphite depends on its structure and the size and toughness of the particle almost as much as on its carbon content. Crucible-grade graphite ranges in size from 20 to 50 mesh. Flakes larger than 20 mesh decrease the density of the crucible and thus detract from its strength, and flakes smaller than 50 mesh do not have enough covering power to make a satisfactory crucible. The following table gives the carbon content and flake size of the various grades of flake graphite:

Classification of flake graphite

Percentage on -	+20	+30	+40	+50 mesh	Tolerance percent	Carbon content, percent
1A	8	20	40	27	5	85
1		15	20	60	5	85
2	90 percent through -50 on +70				10	85
3	90 percent through -70 on +100				10	80
4	100 percent through -100 mesh				10	65

The purest commercial natural graphite is Ceylon crystalline lump and chip vein graphite. Vein graphite is graded as needle lump, lump, chip, and dust. Needle lump, because of its fibrous structure, is a special quality material and contains 90 to 95 percent carbon; lump ranges in size from a walnut to a pea and contains about 90 percent carbon; chip ranges from the size of a pea to a little smaller than wheat grains; and dust is comparable in size to gun powder and smaller and contains 55 to 80 percent carbon. There is also a variety described as large lump (1 to 3 inches), which, although it may contain 91 to 99 percent graphitic carbon, does not have the structure desired for making crucibles and usually sells for a lower price than crucible lump.

Amorphous graphite is often graded according to the locality from which it comes, as each deposit has its local peculiarities. As mined, it ranges in size from about half an inch to dust. Most amorphous graphite is the result of the metamorphism of coal seams, the carbon of which has been converted into the graphitic form. The purity of such graphites, therefore, is dependent on that of the original coal. Amorphous graphite is also found finely disseminated in slates and shales. These graphitic slates, as a rule, are relatively low in carbon, and some of them are too lean for refining. In such deposits the ore is hand-picked and ground for use in paints and foundry facings. The high-grade amorphous deposits, as for example those of Sonora in Mexico, average 86 percent carbon.

USES

Natural Graphite

The value of graphite to industry is based upon suitable application of one or more of its inherent qualities, such as unctuousness (which is often incorrectly referred to as greasiness); refractoriness, or ability to withstand high temperatures; conductivity of heat and electricity; inertness to a large range of reagents; and miscibility with other materials and with liquids. It is used in the manufacture of graphite crucibles, stove polish, lubricants, paints, lead pencils, foundry facings, dynamo brushes, electrodes, dry batteries, fertilizers, and many less important articles.

Crucibles. - The fair thermal conductance and high melting point of g graphite are the characteristics that qualify it for a number of refractory uses - the manufacture of crucibles, crucible covers, pouring nozzels, crucible rests and stools, funnel or extension tops, skimmers, phosphorizers, ladle stoppers and stopper sleeves, pyrometer sleeves, furnace bricks and doors, annealing boxes, and case-hardening containers. For this purpose, Madagascar flake has been specified as essential. When mixed with clay and sand, and later fired, graphite imparts a resistance to sudden heat changes and a degree of heat conduction unequalled by most metals.

Foundry facings. - Small flake of comparatively low carbon content and amorphous graphite are used for foundry facings. Except for the universal requirement of extreme fineness, the preparation of facings follows no generally accepted standard; therefore, there are probably as many formulas as there are manufacturers. The usual practice is to mix the graphite with sand, clay, talc, or mica. These impurities are present in many low-grade graphites, and therefore very little refining is necessary in the preparation of this commodity.

Lubricants. - Graphite is valuable as a lubricant because it adheres readily to metal surfaces and fills the pores, thus giving a veneer that reduces the bearing coefficient of friction virtually to that of graphite itself. The veneer is also protective, being resistant to most chemical and corrosive reactions. Flake graphite is preferable, as it readily forms a scaly layer on the metal, which is essential for successful solid lubrication, whereas extremely fine graphite tends to flow excessively with the oil supplied to the bearing. Graphite is also used for dry lubrication where oil or grease might be detrimental and where liquids of all sorts are to be avoided, as, for instance, on the bridges of pianos, organs, and textile machines.

Paints. - Any impure natural graphite may be used in the manufacture of paints. Pure graphite is unsuitable, as it tends to coagulate in the oil vehicle and spread under the brush into an excessively thin coating. Impure graphite containing substantial quantities of silica can be mixed with iron oxide or zinc compounds to make a satisfactory pigment for paints employed for the protection of bridges, railroad cars, smoke stacks, boiler fronts, tanks, and metal roofs.

Pencils. - The use of graphite as a pencil or in the manufacture of pancils is one of the earliest and by far the best-known use of this material. In the sixteenth century, crayons were made in England from graphite obtained in the Borrowdale mine in Cumberland. Solid blocks of the natural material were cut into sticks and sold as such. Later, they were cut somewhat smaller and protected by a wooden holder. The present method of making pencil "leads" from a manufactured mixture of graphite and clay began near the close of the eighteenth century. The clay serves as a binder or plasticizer, to facilitate the molding of the graphite, and as a means of regulating the hardness and uniform quality of the "lead."

The Borrowdale mine was exhausted and closed in 1833. Some 15 years later a similar graphite was found in the Sayan mountains west of Irkutsk in Siberia. This became the well-known Alibert mine, which supplied the Faber pencil factory in Nuremburg, Germany, for many years. After this mine was exahusted or abandoned, pencil manufacturers began using different types of graphite. Bohemian grades, which have a reputation for blackness, have been used largely but at present the Mexican amorphous material is in great favor since it can be used without much if any admixture of other graphites.

Although the name "lead pencil" is misleading, finely divided metallic lead is sometimes added together with carbon black or antimony oxide. Although hardness can be regulated by the proportion of clay, it is influenced also by the method of preparation, compression, and other factors.

Miscellaneous. - Amorphous graphite is used as a conducting coating for electrotyping forms. For stove and shoe polishes it is worked into a paste with clay, resin, and soap, an oil or water vehicle being added if a liquid variety is required. Carbon black may be added to intensify the color. Flake graphite is used in compounds employed to prevent scale in boilers. The small flakes gradually penetrate cracks in the scale and intrude between it and the metal, thus making it removable. The amorphous variety or fines from vein or flake graphite may be used to polish shot or to render gunpowde grains waterproof. They are also used as a filler in fertilizers to give the required dark color and to coat the particles, thus preventing absorption of moisture. Similarly, they are used to coat tea leaves and coffee beans to protect them from moisture and to improve their color and general appearance. Flake, vein, or amorphous graphite is used as a dry battery filler. As pure material is required, manufactured graphite is often preferred. Grain size is not important, and of the natural graphites Mexican amorphous is favored by the trade. A new proposed use for graphite is as a smothering or extinguishing medium for fires from incendiary bombs in factories. Graphite is preferable to sand, as the latter would be harmful to machinery.

Manufactured

Manufactured graphite can be used for nearly all purposes where natural graphite is employed, except in manufacturing crucibles. It is virtually the only form of graphite used as electrodes in electrolytic work such as the manufacture of magnesium, chlorine, caustic soda, chlorates, steel ingots, and castings. In colloidal form, as concentrated dispersions in their carriers (water, petroleum, castor oil, glycerine and mineral spirits), it is employed in innumerable lubrication problems, ranging from locks to steam cylinders. Colloidal graphite dispersions likewise impart electrical conductivity, lubricity, opacity, and heat resistance to porous bodies; thus, asbestos packings, industrial soaps, nonfading rayons, and electrical conducting papers are made possible.

MINING AND MILLING NATURAL GRAPHITE

Domestic. - Most of the flake-graphite mines consist of open-pit or quarry operations in the weathered portion of the gneiss or schist. These

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ores are usually beneficiated in three stages - (1) preliminary or coarse grinding in a jaw or gyratory crusher, which separates the larger impurities, (2) refining this concentrate by further grinding in a buhr mill, and (3) a final concentration by flotation. In some deposits in which the country rock is completely weathered to a claylike mass, as in Madagascar, a coarse separation is first made by working in a series of troughs. The second step may be wet or dry grinding in a buhr, rod, or ball mill. A flotation process is believed to be the most efficient means of obtaining a clean concentrate and, at the same time, the maximum amount of large flake, because mechanical sifting will not eliminate all the impurities unless grinding continues to the point where the size of the flake is reduced.[8]

Successful flotation can be achieved with a number of reagents and under a wide range of conditions. The use of a frother alone is usually sufficient to obtain satisfactory separation of fine flakes, but coarse flakes require a small amount of an oily collector to insure their recovery. Depression of the gangue minerals is often more difficult than flotation of the graphite, and acid and alkaline reagents have been used to separate the gangue from the concentrate.[9]

An acid (sulfuric acid) or an alkaline (solium silicate or cyanide) circuit is equally effective as a gangue depressant, and the choice depends on the preference of the operator. It is noted, however, that a strong acid circuit in flotation accentuates the wear on equipment and thus necessitates frequent replacement. The flotation concentrate is filtered and then dried. After drying, the dust is removed by an air separator and the finished product is bagged for shipment.

Mining Ceylon vein graphite involves considerable mining expense, because the veins dip steeply, which necessitates underground operating equipment. Processing vein graphite is comparatively simple and consists of preliminary hand sorting at the mine and later grading by combined manual and machine methods. The first process consists of breaking up the large lumps of graphite by hand as they come from the mines. This eliminates the major portion of the impurities, which are quartz, orthoclase feldspar, pyrite, and other wallrock minerals. The lumps are broken again, and the fragments are rubbed and polished by hand on a piece of wet burlap. The smaller material goes to a sifting machine, which separates it into small lumps, chips, and dust.

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[8] Clemmer, J. B., Smith, R. W., et al., Flotation of Weathered Alabama Graphitic Schists for Crucible Flake: Geol. Survey of Alabama Bull. 49, 1941, 101 pp.

[9] Work cited in footnote 8, p. 73.

Mexico. - Bedded deposits of amorphous graphite in Mexico are typical of the deposits of high-grade graphite of this type. As the beds are folded and pinch and swell on the limbs of the folds, mining is carried on in underground workings. The most successful processing of this type of ore is by grinding and air separation. Among several methods of air separation is one in which the ground material is fed on to cloth bolting stretched over agitating tables whose tops are perforated with a series of holes or jets, through which compressed air is forced. The graphite, which is light, moves off the end of the table, whereas the heavier gangue spills off the side. Another type consists of a vertical stream of air under pressure, which lifts the ground material upward. The gangue, being heavier, falls to the floor, whereas the graphite strikes a curved roof surface and is deposited on an adjacent table.

Amorphous graphite also occurs disseminated in slates, in which it makes up only a small portion of the rock. This material is ground without separation and is sold to the paint trade for use in pigments.

PRODUCTION OF MANUFACTURED GRAPHITE

Commercial production of manufactured graphite began in 1897, when 162,000 pounds of graphite electrods were made by the direct conversion of nongraphitic carbon rods made from a mixture of petroleum coke with tar as a binder. About the same time, the manufacture of graphite in powder form was undertaken, the raw material being anthracite culm or petroleum coke and smaller amounts of quartz sand and sawdust. This material is crushed fine and placed in a long, troughlike furnace having an electrode at each end. On heating, carbides of the various metallic constituents of the ash are formed first; and when the temperature is raised further, they decompose, leaving graphite. A purity of 99 percent carbon is guaranteed.

For lubricating purposes it is ground to 200 mesh and air-floated. This mass, which is now called disintegrated graphite, is converted to deflocculated or colloidal graphite by treatment with a solution of tannic acid. The graphite is then suspended in water and allowed to settle for several days, and is then decanted and passed through a filter press to form a paste consisting of graphite and water in approximately equal proportions. From this paste, an oil suspension is produced by grinding in a pug mill with continual small additions of oil until all the water has been displaced and a product known to the trade as Achesons "Oildag" is obtained. Colloidal graphite is similarly dispersed in water, castor oil, glycerine, naphtha, and mineral spirits. The entire output of manufactured and colloidal graphite is produced by the International Acheson Graphite Co. of Niagara Falls, N. Y., and Ontario, Canada.

DOMESTIC CONSUMPTION

Most of the natural graphite consumed in the United States consists of imported flake, lump, chip, and amorphous material from Madagascar, Ceylon, and Mexico, respectively. Consumption of both natural and manufactured graphite has fluctuated considerably during the past 30 years, but definite trends are discernible. The consumption of flake, lump, and chip have declined, whereas amorphous and manufactured have increased, particularly since the outbreak of the war.

From 1913 to 1918, the crucible makers, who accounted for more than 50 percent of the high-grade lump and chip consumed, insisted upon the use of Ceylon graphite. The crucibles manufactured during that period would stand 25 to 28 heats. Thirty years ago, during the war, lack of ships and shipping space created shortages of Ceylon graphite, and the crucible manufacturers turned to Madagascar flake as a substitute. This substitute soon bacame more popular than Ceylon graphite, and consumption of flake increased at the expense of lump and chip. However, with the abandonment of crucible melting by many foundries and steel mills in favor of electrical-furnace or other processes, together with improvement in the manufacture of crucibles, which now stand 40 to 60 heats, considerably less high-grade flake is necessary for industry.

The present war has expanded the need for graphite of all types. It seems probable, however, that this expansion will be temporary and production will decline considerably at the end of the present emergency, not only because peacetime demands for graphite are smaller, but also because of the large stock piles that will have to be dissipated before new supplies are needed. Aside from the crucible grades, crystalline and amorphous graphite are interchangeable in use; and since the deposits of amorphous are more extensive, the use of this type is expanding. The use of manufactured graphite has expanded as the result of greater demand for carbon electrodes and lubricants for war purposes.

TABLE 1. - Principal kinds and sources of graphite used in the United States

Commercial description	Principal uses	Customary sources	Consumption trend
A. Natural crystalline:			
1. Lump and chip 90% C.	Crucibles, ladles, stoppers, and retorts.	Ceylon, 100%	Diminishing
2. Flake 85% C.	Crucibles, carbon brushes, foundry facings, lubricants, dry batteries.	Madagascar, 95% Ceylon, 4% Other, 1%	Fairly large, increasing.
3. Dust 75% C.	Same as amorphous.	Ceylon, 70% Madagascar, 20% Other, 10%	Insignificant.
B. Natural amorphous: 90% C.	Foundry facings, core washes, pencils and crayons, lubricants, paints, shoe polish, dry batteries.	Mexico, 95% Ceylon, United States. Canada.	Large; increasing.
C. Manufactured:			
1. Electrodes, etc. 95% C.	Electric furnaces.	United States, 100%	Do.
2. Powder 95% C.	Dry batteries, lubricants, cummutator brushes, colloidal graphite.	United States and Canada, 100%	Fairly large; stationary.

PRICES AND MARKET REQUIREMENTS

On the domestic market, according to Engineering and Mining Journal Metal and Mineral Markets for July 15, 1943, foreign grades of natural graphite, f.o.b., New York, were priced as follows:

Per pound, Ceylon lump, 10 to 12 cents; carbon lump, 9 to 10 cents; chip, 7 to 8 cents; dust, 4 to 5 cents; Madagascar flake, 9 to 10 cents; prices nominal.

No. 1 flake, 9 to 16 cents; No. 2, 7 cents upward; fine-ground, 55 to 70 percent carbon, 3 cents upward; amorphous, 3 cents upward.

Crude amorphous graphite f.o.b. New York, $14 to $30 per ton, according to grade.

Mexican amorphous graphite 85 percent carbon is sold for $10 to $15 per ton f.o.b. mine, Sonora, Mexico.

Prices of domestic graphite are controlled by the Office of Price Administration general maximum price regulation and may vary with individual operators. The Metals Reserve Co. price list per pound, for domestic flake of specific grades is as follows: No. 1A, 14 cents; No. 1, 13 cents; No. 2, 11 cents; No. 3, 7 cents and No. 4, 5 cents.

Amorphous graphite ranges from 2 to 4 cents per pound, depending on the carbon content.

As all the manufactured graphite is produced by one company, prices for this material do not appear on the open market.

The majority of graphite buyers in the United States are reluctant to experiment with domestic grades, having long been accustomed to standard foreign material. Thus, even in the rare instances in which good natural graphite is found, commercial production must await development of a profitable market. However, experiments are being carried on by crucible manufacturers in an effort to make crucibles from domestic flake that will be acceptable to the trade. Specifications of crucible-grade graphite vary with the individual manufacturers; however, general specifications for such material call for flake graphite that is virtually 100 percent between 20 and 50 mesh and 75 percent through 28 and on 35 mesh. Carbon content ranges from 85 to 90 percent, and bulk density is such that 100 grams of the material will occupy a minimum volume (after repeated jolting and tapping on a table top) of 129 cc. A 250-cc. cylindrical graduate is used in making this test, and readings are taken at 2-minute intervals until constant within less than 1 cc.

Army, Navy, and Federal specifications for graphite used in lubricants follow:

United States Army Specification No. 2 - 34A, April 21, 1939. Graphite. This specification covers one grade of graphite for use as a dry lubricant and for compounding with lubricating greases and oils. Unless otherwise specified, either natural or manufactured graphite may be furnished. The material shall be a dry powder free from any indication of caking or lumping. Ash content shall not exceed 1.0 percent. Total carbon shall not be less than 98 percent. No residue shall be retained on a 100-mesh screen. Not more than 2.0 percent shall be retained on a 200-mesh screen. On rubbing the residue on the 200-mesh screen on two flat, polished, brass plates, no scratches shall be visible (without magnification). Nongraphitic carbon shall not be present in sufficient quantity to be detectable when tested in the following manner:

One gram of graphite is shaken with 1 ml. of liquid of 1.90 plus or minus 0.01 specific gravity and suitable solvent and wetting power. A mixture of chloro- and bromo-hydrocarbons is suitable. The suspension shall then be allowed to stand or be centrifuged until the liquid clears. No visible quantity of material shall float on the surface of the liquid.

Navy Department Specification 14G5, September 2, 1941. Graphite, lubricating. General requirements. - Lubricating graphite shall be furnished in the following grades: Grade II, medium, and grade III, fine. Graphite shall be free from adulteration with oil, grease, lampblack, powdered coal, or other impurities. The ash shall not be abrasive. Detail requirements. - Grade II, maximum ash content 5 percent; minimum graphitic carbon 94 percent; 97 percent shall pass through No. 20 sieve and 75 percent shall remain on No. 100 sieve. Grade III, maximum ash content 2 percent, minimum graphitic carbon 97 percent; 97 percent shall pass through sieve No. 325.

Federal Specifications No. VV-G-671a, February 24, 1942. Grease; Lubricating, graphite. General requirements. - Graphite lubricating grease shall be of fine grades. Grade A, soft; grade B, medium; grade C, hard; grade AA, soft; grade AB, medium. Graphite lubricating grease shall contain no fillers such as rosin, rosin oils, talc, wax powdered mica, sulfur, clay asbestos, or other undesirable or deleterious impurities, and shall contain not more than 0.10 percent of uncombined calcium oxide. Only a slight odor of mineral oil will be accepted, and any other distinct odor shall be sufficient cause for rejection.

Detail requirements. - Graphite lubricating grease shall comply with the following specifications:

	Limit Grade A, soft; grade AA, soft	Grade B, medium; grade AB, medium	Grade C, hard
Ash, as sulfates, percent (maximum)......	5.	7.6	9.5
Moisture, percent (maximum)......	1.5	2	2
Mineral oil content, percent (minimum)	85	80	75
Penetration	300-355	240-290	190-230

POSSIBILITIES FOR DOMESTIC GRAPHITE

It is difficult to generalize about the potential economic importance of the various types of graphite, as the carbon content alone does not determine its value. Other factors, such as its physical form, relative refractoriness, and, in the case of flake graphite, the size and strength of the flake, must also be considered.

American graphite deposits, though numerous and many of them large, are characteristically low-grade. They constitute an abundant source of potential supply but have proved relatively costly to work. Many of the failures in this industry have been due to lack of knowledge of operating costs and an almost complete ignorance of the size and shape of the ore bodies. Mills have been built on the basis of the analysis of a sample that indicates only the value of the sample and which might not be taken as an average for the deposit. Other factors of equal importance are the size of the deposit, the associated minerals, the ease or difficulty of separation of the graphite from the gangue, and the availability of a market for the finished product. The use of the product determines the extent and the cost of beneficiation of the raw material.

As a result of the work of the Federal Geological Survey and the Bureau of Mines it is estimated that 300,000 short tons of graphite is available in Pennsylvania and Alabama, 25,000 tons of which is flake graphite. With present mining and milling equipment, this flake can be produced at the rate of 4,300 short tons annually. According to present specifications of crucible manufacturers this material is too small or soft to make crucible acceptable to the trade. However, it is applicable in all the other uses cited, and industry is experimenting to make satisfactory crucibles from domestic flake.

DOMESTIC GRAPHITE PRODUCERS

Alabama;

Alabama Flake Graphite Co., Ashland.
Ceylon Graphite Co., Goodwater.
Crucible Flake Graphite Co., Ashland.

Michigan:

Detroit Graphite Co., 550 12th St., Detroit. (Mine at L'Anse.)

Montana;

Fenner & Riebhoff, Whitehall.

Nevada:

Carson Black Lead Co., Carson.

New Jersey:

Benjamin Franklin Graphite Co., P. O. Box 203 Milltown.

New York;

Acheson Graphite Co.,[10] 30 E. 42d St., New York City.
St. Lawrence Graphite Co., Morristown.

Rhode Island;

Graphite Mines, Inc., P. O. Box 93, Cranston.

Texas:

Southwestern Graphite Co., Burnet.

GRAPHITE BUYERS

California;

Marshall Dill, 510 Montgomery St., San Francisco.
Pacific Graphite Works, 40th & Linden Sts., Oakland (amorphous or flake).

Connecticut;

American Crucible Co., Shelton.

Illinois, Chicago;

S. Obermayer Co., 2559 West 18th St. (crude).
Otley Paint Mfg. Co., 1742 N. Winchester Ave., (amorphous).
Superior Flake Graphite Co., 1531 First National Bank Building.

Massachusetts:

Springfield Facing Co., Springfield (amorphous).

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[10] Manufactured.

Michigan:

Cummings Moore Graphite Co., 1646 Green St., Detroit (amorphous crystalline, or Ceylon flake, artificial).

Minnesota:

Forster Paint & Mfg. Co., Winona (amorphous, flake).

New Jersey:

American Lead Pencil Co., Hoboken.
Asbury Graphite Mills, Asbury (flake and powdered).
Bloomsbury Graphite Co., Bloomsbury (amorphous, flake).
Joseph Dixon Crucible Co., Jersey City.
J. H. Cantier & Co., 1-10 Greene St., Jersey City (amorphous, flake).

New York:

Garlock Packing Co., 250 Main St., Palmyra (ground).
Ward's Natural Science Establishment Inc., 320 N. Goodman, Rochester.
Williamson Graphite Co., 149 Columbia Heights, Brooklyn (ground and refined).

New York City:

American Cyanamid & Chemical Corporation, 30 Rockfeller Plaza.
H. J. Baker & Bros., 271 Madison Ave.
Barclay Chemical Co., Inc. 75 "A" Varick St.
Eagle Pencil Co., 703 East 13th St. (amorphous, flake).
Gerard-Kluyskens Corporation, 261 5th Ave.
Adolphe Hurst & Co., 323 West 42d St.
Ilsley Doubleday & Co., 229 Front St. (crude and ground).
International Selling Corporation, 70 Pine St.
Chas. Mathieu, Inc., 120 Liberty Ave.
Chas. Pettinos, 1 East 42d St. (all kinds).
Whittake, Clark & Daniels, Inc., 245 Front St.

Ohio:

Hill & Griffith, 1265 State St., Cincinnati.
Smith Facing & Supply Co., 1857 Carter Road, Cleveland (amorphous).

Pennsylvania:

J. S. McCormick Co., 25th & A. V. Railroad, Pittsburgh.
Paxson Co., Inc., 1206 Locust St., Philadelphia (amorphous or flake).
Geo. F. Pettinois, Inc., 1206 Locust St., Philadelphia.
Ross-Tacony Crucible Co., Robbins & Milnor, Philadelphia. (flake).

BIBLIOGRAPHY

There follows a partial list of publications that discuss the uses of graphite. Most of these are available in college, engineering, or public libraries.

ARSEM, W. C. Transformation of Other Forms of Carbon into Graphite. Trans. Electrochem. Soc., vol. 20, 1911, pp. 105-119.

ASHLEY, G. H. Rhode Island Coal. Geol. Survey Bull. 615, 1915; Graphite Deposits, pp. 18-20, 33, 57.

BASTIN, EDSON S. Origin of Certain Adirondack Graphite Deposits. Econ. Geol., vol. 5, 1910, pp. 134-157.

_______________ The Graphite Deposits of Ceylon. Econ. Geol., vol. 7, 1912, pp. 419-443.

BOHNE, E. Der Bergbau der deutschösterreichischen Alpenlander. Ztschr. Berg- Hutten- und Salinenwesen, Bd. 70, Abhand. 2, 1922, pp. 75-98. Geol. Karte., Berlin, 1922.

BROWN, JOHN S. Graphite Deposits of Ashland, Ala. Econ. Geol., vol. 20, No. 3, May 1925.

BUREAU OF MINES. Minerals Yearbook, annual volumes, Minor Nonmetal chapters.

CLARK, THOMAS H. The Origin of Graphite. Econ. Geol., vol 16, No. 3, Lancaster, Pa., May 1921, pp. 167-183.

CLEMMER, J. B., SMITH, R. W., and others. Flotation of Weathered Graphitic Schists for Crucible Flake. Geol. Survey of Alabama Bull. 49, 1941, 101 pp.

COE, G. D. The Burning Rate of Natural Graphite. Bureau of Mines Rept. of Investigations 3692, 1943, 9 pp.

DONATH, E., and LANG, A. Ueber die Untersuchung und Wertbestimmung des Graphits: Montan. Rundschau, vol. 7, 1915, pp. 653-658, 683-687; Stahl u. Eisen, vol. 34, 1914, pp. 1757-1761, 1848-1852; Chem. Abs., vol. 9, 1915, pp. 1158-1159.

DUB, G. C., and Moses, F. G. Mining and Preparing Domestic Graphite for Crucible Uses: Bureau of Mines Bull. 112, 1920, 80 pp.

FERGUSON, H. G. Graphite. Geol. Survey Mineral Resources, 1916, pt. II, 1917, pp. 43-59.

FITZGERALD: F. J. (Chemist of the International Acheson Graphite Co.) The Conversion of Amorphous Carbon to Graphite. Jour. Franklin Inst., vol. 154, 1902, pp. 321-348.

GANDRUD, B. W., COE, G. D., and others. The Flotation of Alabama Graphite Ores. Bureau of Mines Rept. of Investigations 3225, 1934, 20.pp.

HESS, F. L. Graphite Mining near La Colorada, Sonora, Mexico. Eng. Mag., vol. 38, 1909, pp. 36-43.

HORNADAY, W. D. The Santa Maria Graphite Mines, Mexico. Min. and Eng. World, December 7, 1912.

KEMP, J. F. Graphite in the Eastern Adirondacks, N. Y. Geol. Survey Bull. 225, 1904, pp. 512-514.

LEE, WILLIS T. Graphite near Raton, N. Mex. Geol. Survey Bull. 530, 1913, pp. 371-374.

MILLER, B. L. Survey of the World Graphite Situation. Min. and Met. Soc. Bull. 226, 1933, pp. 101-112.

PAIGE, SIDNEY. Graphite in the Llano-Burnet Region, Texas. Geol. Survey Bull. 450, 1911, pp. 77-82.

PARSONS, C. S. The Concentration of Flake Graphite Ores. Canadian Min. Jour., vol. 19, No. 39, September 28, 1928, pp. 778-781.

PAVLOV, M. A. Graphite Deposits in the Russian Far East. Ann. Rept. Geol. Com. Russ. Far East for 1926, Suppl. 4, Geol. Com. Russ. Far East, Records, No. 50, Vladivostok, 1927, pp. 48-50. (In Russian).

PROUTY, W. F. Geology and Distribution of Graphite in Alabama. Alabama Geol. Survey Bull. 19, 1917.

SHEELEY, J. W. Graphite in Madagascar. Min. Mag., vol. 14, 1916, pp. 324-330.

SMITH, EUGENE A. Graphite in Alabama. Mineral Ind., vol 16, 1907, pp. 567-568.

SPENCE, HUGH S. Graphite. 1920, 202 pp.

TYLER, PAUL M. Graphite. Part 1. Bureau of Mines Inf. Circ. 6118, 1929, 45 pp.

________________ Graphite. Part II. Domestic and Foreign Deposits. Bureau of Mines Inf. Circ. 6122, 1929, 25 pp.

________________ Graphite. Part III. Utilization of Graphite. Bureau of Mines Inf. Circ. 6123, 1929, 20 pp.

________________ Graphite. Part IV. Status of the American Graphite Industry. Bureau of Mines Inf. Circ. 6124, 1929, 14 pp.

________________ Marketing Graphite. Bureau of Mines Inf. Circ. 7177, 1941, 12 pp.

WINCHELL, ALEXANDER V. Graphite near Dillon Mont. Geol. Survey Bull. 470, 1911, pp. 523-532.

ZIMMERMANN, MAURICE. La Production du graphite dans le monde. Ann. geol., vol 29, Annee 160, July 15, 1920, pp. 304, 306.